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ORIGINAL ARTICLE

Food cravings and energy regulation: the characteristics of craved foods and their relationship with eating behaviors and weight change during 6 months of dietary energy restriction

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Objective: To examine characteristics of craved foods in relation to dietary energy restriction (ER) with high (HG) and low glycemic load (LG) diets.
Design: Assessments of food cravings before and during a randomized controlled trial of HG and LG diets provided for 6 months.
Subjects: Thirty-two healthy, overweight women aged 20–42 years.
Measurements: Self-reported food cravings and dietary intake, body weight, weight history and measures of eating behaviors.
Results: Foods craved at baseline were more than twice as high in energy density as the habitual diet (3.7 ± 1.5 vs 1.7 ± 0.3 kcal/g; $P < 0.001$), and on average were lower in protein ($P < 0.001$) and fiber ($P < 0.001$) and higher in fat ($P = 0.002$). There were no statistically significant changes in nutritional characteristics of craved foods after 6 months of ER. There was a significant relationship between reported portion size of craved food consumed at baseline and lifetime high body mass index ($r = 0.49$, $P = 0.005$). Additionally, there was a significant association between susceptibility to hunger and craving frequency at baseline, and there were significant relationships between hunger score, craving frequency, strength and percentage of time that cravings are given in to after 6 months of ER. In multiple regression models, subjects who lost a greater percentage of weight craved higher energy-dense foods at month 6 of ER, but also reported giving in to food cravings less frequently (adjusted $R^2 = 0.31$, $P = 0.009$).
Conclusion: High energy density and fat content, and low protein and fiber contents were identifying characteristics of craved foods. The relationships between craving variables and hunger score suggest that the relative influence of hunger susceptibility on cravings may be important before and especially after ER. Portion size of craved foods and frequency of giving in to food cravings appear to be important areas for focus in lifestyle modification programs for long-term weight loss.
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Keywords: food craving; weight loss; energy density; energy restriction

Introduction

Food cravings, typically defined as 'an intense desire to eat a specific food'[1] have been reported in 52–97% of individuals studied.[2–6] The frequency, strength and types of food cravings have been found to differ between men and women,[6] different phases of the menstrual cycle[7] and in some cases with body mass index (BMI).[8–10] However, the origins of cravings and their importance in the etiology and treatment of obesity remain uncertain.

Although the underlying causes of food cravings remain poorly understood, there have been a number of theories concerning their origin. Some have focused on biological underpinnings of food cravings and have explored the possibility that cravings represent a learned appetite for energy that develops, for example, through the reinforcing

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effects of eating particular foods when hungry.[11,12] Neurological explanations for reinforcement include responses to eating mediated by the release of dopamine in the nucleus accumbens and neostriatum[13,14] or altered endogenous opioid peptide synthesis and release, which have been proposed to induce food cravings by increasing perceptions of palatability.[15] However, other studies have suggested that food cues and sensory stimulation increase food cravings and intake whether in a hungry or satiated state,[16,17] indicating a role for post-ingestive conditioning independent of any metabolic need for food. The latter suggestion is also supported by reports that factors such as mood and food imagery are common antecedents to food cravings.[18–20] More recently, it has been suggested that cravings may increase with dietary monotony without energy restriction (ER);[21,22] however, such suggestions appear to be contradicted by other studies using monotonous diets to achieve ER that have observed decreases in cravings.[23,24]

The role of food cravings in the success, or lack of success, with dieting is also uncertain. Previous data have suggested that a short-term reduction of energy intake may increase the relative reinforcing value of food.[25] However, mixed results have been found when looking at the effect of longer-term weight loss diet interventions on food cravings.[19,23,24,26] Some studies have reported a decrease in cravings with consumption of low-energy diets, especially monotonous programs.[23,24,26] However, this observation is seemingly at odds with the separate finding that missing favorite foods is a commonly cited cause of giving up a weight loss diet.[27,28] Differences in study design, in particular the use of cross-sectional vs longitudinal data, may have contributed to the inconclusive results obtained to date. Also, very few studies have measured both reported food cravings and actual dietary intake, and therefore have not been able to determine whether foods reported as craved foods are actually consumed in the diet and if the intake of craved foods actually changes with weight loss.

The study described here was conducted as part of the Comprehensive Assessment of Long-term Effects of Reducing Intake of Energy (CALERIE) study, which is a randomized controlled trial designed to examine the long-term effects of dietary ER leading to sustained weight loss. Described here are longitudinal changes in food cravings in response to 6 months of ER with provided low (LG) and high glycemic (HL) load diets. CALERIE was a 1-year pilot study with a primary goal to identify dietary regimens that subjects can tolerate at prescribed ER levels for long-term studies. In addition, a secondary outcome was to assess aspects of eating behaviors, such as food cravings, and how they relate to body weight, ER adherence and energy intake. We hypothesized that craved foods are significantly higher in energy density than non-craved foods, and that long-term exposure to dietary patterns consistent with weight loss will lead to changes in the characteristics and consumption patterns of craved foods.

Methods

Subjects

The subjects in this analysis were 32 overweight (BMI = 25–30 kg/m^2) but otherwise healthy women, aged 20–42 years. They were part of the sample of men and women ($n = 46$) who participated in the CALERIE trial at Tufts University, a 12-month study of ER. Owing to the small number of men in the CALERIE trial and reported differences in craving characteristics between men and women,[4,6,29] only women were used in the current analysis. We also used only the first 6 months of data from the trial, because subjects were provided with all meals and snacks during this period, giving us a greater confidence in the dietary intake data. Out of the 34 female participants who were enrolled in ER, two dropped out before 6 months, leaving 32 subjects for the current analysis.

Subjects were enrolled as healthy individuals free of diseases that might have influenced outcomes (including diabetes, cancer, coronary heart disease, endocrine disorders, a psychiatric diagnosis or eating disorder) and did not use medications that would influence energy intake or metabolism. Eating disorders were assessed using the Eating Disorder Examination.[30] The following were also criteria defining ineligibility for the study: high dietary restraint scores (>17) measured by the Eating Inventory,[31] very high activity levels (participation in sports or training for greater than 12 h/week), unable to complete a plausible dietary record during screening (defined as a reported energy intake in a 7-day record within 30% of the calculated estimated energy requirements based on the dietary reference intake equations),[32] reported weight gain or loss of >6.8 kg in the previous year, and anticipated lifestyle changes over the following year such as pregnancy or moving out of state.

The study was conducted from the Metabolic Research Unit of the Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University with approval by the Institutional Review Board of Tufts-New England Medical Center. All subjects gave written, informed consent before participating, which included consent to the use of data collected in screening, and were provided a stipend for their time.

Study protocol

Baseline energy requirements were determined as total energy expenditure measured using the doubly labeled water (DLW) technique[33] during a 7-week weight-stable baseline period when subjects ate their usual diet at home and visited the research center at intervals to complete baseline outcome testing. Subjects were then randomized to two diets: either a HG diet (60% carbohydrate, 20% protein, 20% fat, fiber 15 g/1000 kcal, mean estimated daily glycemic index (GI) of 86 and glycemic load (GL) of 116 g/1000 kcal) or a LG diet (40% carbohydrate, 30% protein, 30% fat, fiber 15 g/1000 kcal, mean estimated daily GI of 53 and GL of 45 g/1000 kcal) and both groups were fed at either 10 ($n = 7$) or 30% ($n = 25$) ER compared to baseline individual assessment of usual energy

needs. Note that fewer subjects were enrolled into the 10% ER groups intentionally, because the primary purpose of these groups was to gain experience with recruiting a population for a low level of ER. The diets were matched in energy density (1 kcal/g for the mean of daily menus) and palatability, measured using analog scales to assess taste tests of study foods, was equivalent in pilot testing of the diets.[34] Subjects were provided with all food and energy-containing beverages to meet their ER energy prescription during the 24-week food-provided phase, and they or a family member came to the metabolic research unit twice weekly to collect all of their study food.

Outcome measurements

Height, body weight and composition. At baseline, height was measured using a wall-mounted stadiometer to ± 0.1 cm. Fasting weight was measured weekly to ± 0.01 kg using a calibrated scale (DETECTO-Cardinal Scale Manufacturing Co. Model CN-20, Webb City, MO, USA). BMI (kg/m^2) and percent weight change were calculated using the mean of duplicate weights taken at two different visits at baseline and at month 6 of the study. To have an assessment of weight history, each volunteer also completed a questionnaire which included information on average and highest weight for ages 20–29, 30–39 and 40–49.[35] These reported weights, along with a measured baseline height and weight, were used to calculate each volunteer's adult lifetime high BMI, which was used to look at the relationship between history of weight gain and food cravings. Air displacement plethysmography (BOD POD, Life Measurement Inc., Concord, CA, USA) was used to measure body density and to determine percent body fat at baseline and 6 months. The procedure and validation of this method are described elsewhere.[36,37]

Baseline physical activity levels at baseline

Complete details of these measurements are described elsewhere.[34] Briefly, resting metabolic rate (RMR) was measured in duplicate (on two consecutive mornings) by indirect calorimetry (Deltatrac portable metabolic cart, Sensor Medics Corp., Yorba Linda, CA, USA), after the subjects slept overnight in the research center and after a 12 h fast. Total energy expenditure (TEE) of the subjects was measured using DLW over two successive 14-day periods at baseline, and physical activity level (PAL) was calculated by dividing the mean baseline TEE by the mean baseline RMR.

Food craving battery

The Craving Questionnaire developed by Weingarten and Elston (1991),[4] which includes questions about food cravings and how often cravings lead to eating the desired food was combined with a food craving questionnaire developed by Hill (1991),[18] which uses visual analog scales to assess the frequency and strength of food cravings. This food craving battery which combed the two published questionnaires was administered at baseline and at month 6.[4,18] The battery defined food craving as 'an intense desire to eat a specific food'. Volunteers were defined as 'cravers' if they answered yes to the question 'Have you experienced food cravings over the past 3 months?' Details on the strongest craving were collected, including type of food, frequency (times/month) of craving for the strongest craved food and percentage of time the volunteer gave in to the craving. The questionnaire also instructed subjects to 'Describe in as much detail as you can the food you crave the most'. The reported frequency (times per month) of the strongest craving was multiplied by the percent time that the volunteers reported they gave in to cravings to calculate an estimated frequency of consumption of craved foods (times per month). In addition, the food craving battery used 100 mm visual analog scales to assess the frequency (two questions) and strength (three questions) of cravings. The scales were 5-point anchored scales with descriptors such as 'never' to 'daily' or 'extremely weak' to 'extremely strong' at opposite ends. The mean of each set of questions was calculated to derive mean craving strength and frequency scores.[18] If volunteers answered no to the question, 'Have you experienced food cravings over the past 3 months?' at either of the time points, zero values were assigned to frequency and strength of cravings, calories of craved food consumed per portion and reported percentage of time given in to cravings.

Eating Inventory (three-factor eating questionnaire)

The Eating Inventory is a 51-item questionnaire that measures three dimensions of eating behavior: dietary restraint, disinhibition, and susceptibility to hunger and is scored with published guidelines.[31] Subjects completed the Eating Inventory at screening (which served as the baseline measure) and at month 6. Restraint, disinhibition and hunger scores were calculated at each time point.

Dietary intake and characteristics and consumption of strongest craved foods

The 7-day food record collected during the screening phase of the study[32] was used as a baseline measure of habitual food intake. During the 6-month food provided phase of the study, volunteers completed a daily meal checklist to confirm provided food and to quantify any leftover and additional consumed food. Seven consecutive days of these meal checklists that were collected at the end of month 6 (week 23) were used to estimate food intake for the month 6 time point. Nutrient calculations were performed using the Nutrition Data System for Research (NDS-R) software version 4.05_33, developed by the Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN, Food and Nutrient Database 33, released 2002.[38]

The subjects' strongest craved foods (as identified on the food craving battery) were identified in their 7-day food

records at screening and from non-study foods consumed at month 6. The subjects' description of each strongest craved food was used to identify foods within the reported food records and meal checklists that matched the food description. When a food description was very specific (for example, salt and vinegar potato chips by brand name), then either the specific food or closest nutritional match was entered. For the food descriptions that were more general (for example, potato chips), a more general description using NDS-R defaults were used (chips – snack type, potato, unknown type, unknown if salted, unknown if regular or thick cut and ingredient of fat not known). The nutrition information from the NDS-R default food descriptions are based on nationally representative market research data.[38] The frequency with which each volunteer consumed a craved food was obtained at each time point by counting the number of times a craved food appeared in the 7-day food record from screening and from the 7 days of meal checklists at month 6. If the same type of food was eaten twice at one meal (for example, two pieces of chocolate), this was counted as one occasion. The estimated frequency of craved foods eaten per month was then calculated from the number of craved foods that appeared in the 7-day diet records at each time point. The calories per portion of craved food eaten were also calculated at each occurrence that a craved food was reported in the food record.

Common nutritional characteristics of the habitual diet were computed from the 7-day diet records, including energy density (kcal/g), macronutrient content, and sugar and total fiber content. The combination of fat and carbohydrate (expressed as a percent of total energy in the food from these two macronutrients) was also calculated to explore further the defining characteristics of craved foods vs the habitual diet. The 7-day mean energy density and macronutrient distributions were calculated for each subject with NDS-R. Energy density values can widely differ depending on calculation methods[39,40] and because of the influence of beverages on energy density calculations, the nutrient characteristics of the habitual diet were calculated from the diet records both with and without beverages included. In these calculations, a beverage was defined as all energy-containing and energy-free liquids that were consumed as a beverage, which included any additions to the beverages (such as sugar, sweetener, and so on). If milk was consumed along with cereal or if a liquid was part of a food recipe then it was counted as a food, not a beverage. These same nutrition variables were computed for subjects' strongest craved foods that were reported on the food craving battery, by entering the strongest craved foods at each time point into NDS-R.

Statistics

All statistical analyses were performed by using SAS software (version 9.1 SAS Institute, Cary, NC, USA) and Systat software (version 11.0 Systat Software Inc., Richmond, CA, USA). All values are expressed as means$\pm$s.d., unless otherwise indicated. Paired *t*-tests were used to compare changes within subjects over time between baseline and month 6. Independent *t*-tests and analysis of variance were first used to assess any difference between any of the randomization groups (diet composition and ER level). Linear regression and Pearson correlation coefficients were calculated to assess the relationship between food cravings and factors of eating behavior and BMI. Predictors of weight loss were assessed simultaneously with multiple regression. All *P*-values were two-sided and considered to be statistically significant if less than 0.05.

Results

Subject characteristics

Table 1 shows subject characteristics at baseline and after 6 months of ER. There were statistically significant decreases in weight and BMI after 6 months of ER, but there was no statistically significant difference in weight loss between the 10 and 30% ER groups, and there was no statistically significant effect of diet composition on weight loss.[34] Since weight loss did not differ between groups and no differences in craving variables were found among randomized groups, all diet and ER groups were combined for subsequent analyses.

Characteristics of cravers

Out of the 32 women, 29 women at baseline and 30 women after 6 months of ER reported that they experienced food cravings over the past 3 months. Table 2 shows the characteristics of food cravings for those women who reported cravings over the past 3 months. At both baseline and month 6, diet records indicated that subjects consumed craved foods more frequently than they reported on the food craving battery (perhaps due to underreporting of cravings, or to consuming these foods both due to and independent of cravings). However, the statistically significant decrease in reported percent of time volunteers gave in to cravings after

Table 1 Subject characteristics[a]

	Baseline	*Month 6*	P-*value*[b]
N	32	32	
Age (years)	35.0$\pm$5.0		
Height (cm)	165.5$\pm$7.3		
Weight (kg)	76.3$\pm$7.8	69.6$\pm$7.7	$<$0.001
BMI (kg/m^2)	27.8$\pm$1.4	25.4$\pm$1.9	$<$0.001
Body fat (%)	38.1$\pm$5.2	32.6$\pm$6.2	$<$0.001
Restraint score	10.3$\pm$4.0	12.3$\pm$3.5	0.002
Disinhibition score	7.2$\pm$2.8	7.1$\pm$3.1	NS
Hunger score	4.5$\pm$2.3	4.0$\pm$2.5	NS

Abbreviations: BMI, body mass index, NS, not significant. [a]Means$\pm$s.d. [b]Paired *t*-tests comparing baseline to month 6.

Table 2 Characteristics of individuals reporting food cravings[a,b]

	Baseline	*Month 6*	P-*value*[c]
From craving questionnaire			
Percent of time give in (%)	64.4±23.5	26.5±23.4	<0.001
Frequency of strongest craving (times/month)	8.2±8.1	9.8±9.9	NS
Calculated frequency of consumption of craved foods[d] (times/month)	5.6±7.0	2.7±4.1	0.06
Percent who relate craving to menstrual cycle %)		86	76
Craving frequency score (100 mm visual analog scale)	36.2±19.8	34.9±20.3	NS
Craving intensity score (100 mm visual analog scale)	50.1±14.3	49.0±16.4	NS
From food record			
Percent of cravers who reported craved foods in 7-day diet record (%)	79	57	
Frequency of consumption of craved foods (times/month)	22.2±21.5‡	7.0±8.4‡	0.001
Mean portion size of consumed craved food (kcal/portion)	177.3±151.9	116.6±200.8	NS
Mean daily % energy intake from most craved food	7.0±6.1	6.5±11.3	NS

Abbreviation: NS, not significant. ‡$P<0.01$ paired *t*-test to compare actual intake of craved foods (from food record) compared to calculated intake (times/month × percent time give in) reported on questionnaire at each time point. [a]Means±s.d. [b]Includes only those who said yes to 'Have you experienced food cravings over the past 3 months?' at respective time points. ($N=29$ at baseline, $N=30$ at month 6). [c]Paired *t*-test comparing baseline to month 6, includes subjects answering yes to cravings at both time points. [d](Frequency of craving) × (Percent time give in).

6 months of ER was reflected in the decrease in reported frequency of eating craved foods at month 6 on both the food craving battery and in the diet record.

There was a statistically significant association between the reported portion of craved food consumed at baseline (from the 7-day diet record) and adult lifetime high BMI, as shown in Figure 1. This association persisted when multiple regression was used to control for craving strength, disinhibition, baseline BMI and for total reported energy intake. Frequency and strength of cravings were not significantly related to adult lifetime high BMI (data not shown) and these craving variables as well as portion of craved foods consumed were not associated with current BMI (data not shown). The relationship between the macronutrient distribution of craved foods (ratio of %fat to %carbohydrate) and PAL revealed a trend for less active individuals to crave foods with relatively high fat content; however, this relationship did not reach statistical significance ($r=-0.35$, $P=0.07$, data not shown).

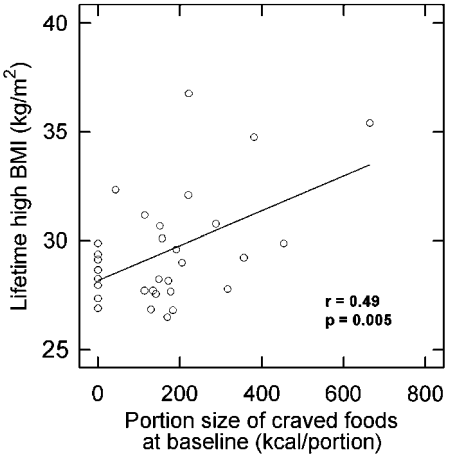

Figure 1 Relationship between portion of craved foods consumed and adult lifetime high BMI. Relationship between adult lifetime high BMI (kg/m^2) and calories of strongest craved food per portion consumed as identified in the baseline diet record. Multiple regression showed that the mean calories of craved food consumed per portion was a statistically significant predictor of adult lifetime BMI ($P=0.03$) while controlling for craving strength, disinhibition, baseline BMI and total energy intake (adjusted $R^2=0.44$, $P=0.001$). BMI, body mass index.

Dietary characteristics of craved foods

The nutritional characteristics of the strongest craved foods and how they compared to the volunteers' habitual diet are shown in Table 3. Foods reported as the strongest craved foods at baseline were found to be more than two times as high in energy density as the habitual diet (without beverages) and on average, were about 50% lower in protein, 30% lower in fiber and 30% higher in fat than the habitual diet. The percent energy from fat and carbohydrate combined was also found to be a characteristic of craved foods, as indicated by the least amount of between-subject variability of all nutrition variables tested at both baseline and month 6 (CV = 0.13, 0.10, respectively). Tested variables that were not significantly different between the habitual diet and craved foods included percent carbohydrate and percent sugar (when including beverages in habitual diet). The nutritional characteristics of craved foods did not change significantly after 6 months of ER. The types and frequency of craved foods at baseline and month 6 are shown in Table 4. The median energy density of craved foods was 4.4 kcal/g at baseline and 3.9 kcal/g at month 6. The 25th to 75th percentiles at baseline and month 6 were 2.6–4.9 and 2.8–4.8 kcal/g respectively, showing that the majority of subjects craved rather high energy-dense foods. Chocolate was the most commonly reported strongest craved food in this group of women, followed by salty snacks. Together, these food

Table 3 Characteristics of strongest craved foods reported on craving battery compared to habitual diet[a,b]

	Craved foods Baseline	*Craved foods[c] Month 6*	*Habitual diet (including beverages)*	P-*value*[d]	*Habitual diet (no beverages)*	P-*value*[d]
Energy density (kcal/g)	3.7±1.5 (0.42)	3.8±1.2 (0.32)	0.8±0.3	<0.001	1.7±0.3	<0.001
% fat	47.3±15.7 (0.33)	44.2±21.0 (0.47)	34.2±5.3	<0.001	36.5±5.6	0.003
% carbohydrate	46.4±18.4 (0.40)	48.5±19.6 (0.41)	48.6±6.3	NS	47.1±6.6	NS
% protein	9.1±9.7 (1.07)	10.2±6.4 (0.62)	17.3±2.4	<0.001	18.0±2.5	<0.001
% sugar	24.0±19.1 (0.80)	16.8±19.5 (1.16)	19.4±4.3	NS	16.5±4.8	0.03
Fiber density (g/1000 kcal)	6.5±3.8 (0.58)	8.1±4.5 (0.55)	9.3±2.6	0.001	9.5±2.5	<0.001
% fat+% carbohydrate	93.7±11.7 (0.13)	92.7±8.8 (0.10)	82.8±3.2	<0.001	83.6±2.8	<0.001

[a]Includes those who answered yes to 'Have you experienced food cravings over the past 3 months?' at respective time points. [b]Means±s.d. (CV). [c]No statistically significant differences between baseline and month 6 craved foods by paired t tests. [d]Paired *t*-tests to compare baseline craved foods to baseline habitual diet.

Table 4 Types of strongest craved foods reported on craving battery[a]

Types and frequency of strongest craved foods	*Baseline*		*Month 6*	
	N	*% of total*	*N*	*% of total*
Chocolate	9	31	6	20
Salty snacks (chips, French fries and nachos)	7	24	7	23
Ice cream	3	10	0	0
Brownies, cookies, cakes and muffins	3	10	4	13
Bread/pasta	3	10	6	20
Meat/fish	2	7	0	0
Ethnic foods (Chinese, Thai and Greek)	1	4	1	3
Iced tea (with tapioca pearls)	1	4	0	0
Pizza	0	0	4	13
Spinach salad	0	0	1	3
Cream cheese	0	0	1	3

[a]Includes those who answered yes to 'Have you experienced food cravings over the past 3 months?' at respective time points.

groups made up over half of the reported craved foods at baseline and over 40% of reported craved foods after 6 months of ER.

Relationship between hunger susceptibility and craving

Significant relationships between the hunger susceptibility score from the Eating Inventory and different food craving parameters were observed at baseline and month 6, as shown in Figure 2. In particular, hunger susceptibility was positively associated with both a craving frequency score (calculated from the visual analog scales) ($r=0.44$, $P=0.01$) and calories of craved food per portion consumed ($r=0.49$, $P=0.004$) at baseline. The association between the susceptibility to hunger and craving frequency persisted after 6 months of ER ($r=0.50$, $P=0.004$), and although not significant at baseline, craving strength and percent time that subjects gave in to cravings were significantly associated with hunger score ($r=0.44$, $P=0.01$, $r=0.45$, $P=0.01$, respectively) after 6 months of ER. There was also a significant relationship between disinhibition and craving strength score at baseline ($r=0.56$, $P<0.01$) and at month 6 ($r=0.39$, $P<0.05$) (data not shown); however, no other statistically significant associations between disinhibition and craving were found at baseline or after 6 months of ER, and no statistically significant associations were found between dietary restraint and cravings for any measure at either time point (data not shown).

Craving variables as predictors of weight change

Multiple regression analyses were performed to explore predictors of percent weight loss after 6 months of ER and the best fitting model is shown in Table 5. After controlling for baseline BMI and age, the reported percentage of time a subject gave in to cravings during the previous 3 months and the energy density of craved foods (both measured at month 6) were both significant predictors of percent weight loss. Subjects with a higher percentage of weight loss (calculated as [(month 6–baseline)/baseline] × 100) craved foods with higher energy densities compared to those who lost a lower percentage of weight, but they also gave in to their food cravings less frequently. The interaction between the percentage of time subjects gave in and the energy density of craved foods at month 6 was not statistically significant ($P=0.33$). In these models, absolute values for percentage of time subjects gave in to cravings and energy density of craved foods were used, instead of change variables, because the questionnaire asked about the past 3 months. A second approach using multiple regression controlling for baseline values was also performed (data not shown) and baseline values were found to be non-significant, with similar overall results.

Discussion

Food cravings have been reported by a majority of individuals in previous studies examining this topic[2,4,5] as well as in the present investigation. However, the extent to which food cravings play a role in the etiology of obesity, and whether successful weight loss requires a reduction in the frequency of experiencing food cravings, remains uncertain.[6,8,10,41,42] The results of this study suggest that portion size of craved foods, but not frequency of experiencing and

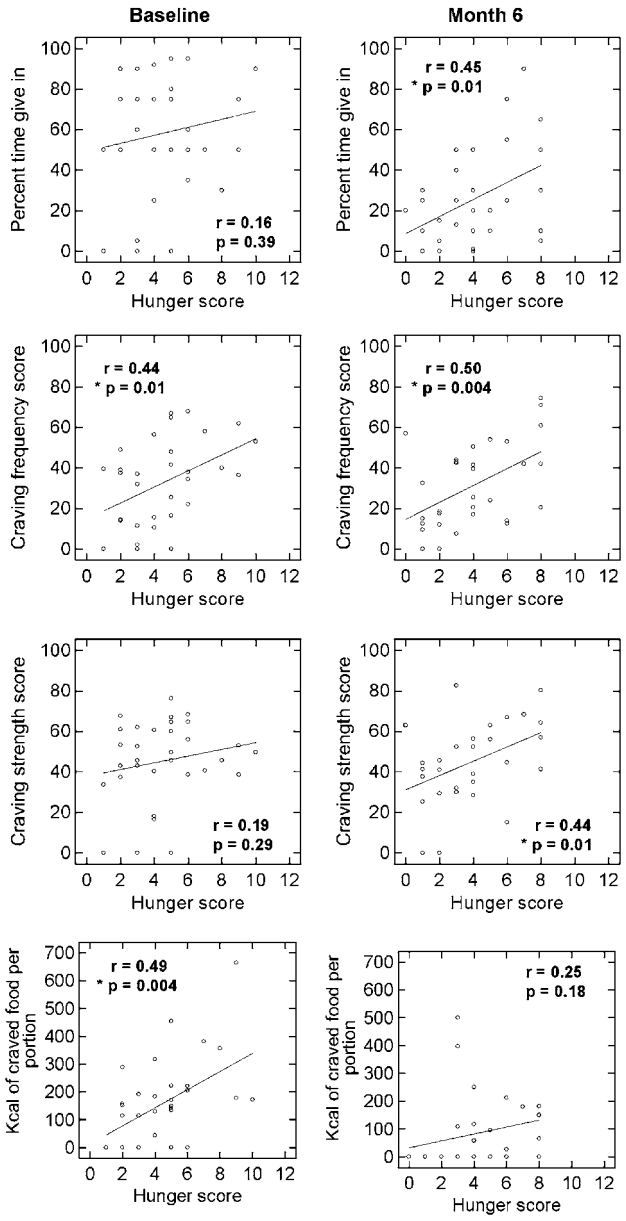

Figure 2 Relationship between the susceptibility to hunger and cravings. Pearson's correlation coefficients shown for relationships between hunger score (scale, 0–14) from the Eating Inventory and variables of food cravings at baseline and after 6 months of energy restriction. The reported percentage of time subjects gave in to craving, craving frequency (0–100 mm visual analog scale), craving strength (0–100 mm visual analog scale) and calories of craved food per portion consumed were considered to be zero for those subjects who answered 'no' to 'Have you experienced food cravings over the past 3 months?' at the respective time points.

giving in to cravings, is a significant predictor of lifetime maximum BMI; however, further longitudinal data are needed to confirm this cross-sectional relationship. In addition, we found that the more successful weight losers had cravings for increased energy-dense foods compared to subjects with less weight loss, but they also had a reduced frequency of giving in to cravings. These findings, combined with previous research, suggest that food cravings are a typical component of human eating behavior and that conscious control of portion size and frequency of giving in to cravings, rather than suppression of food cravings, may be important areas of emphasis in weight control programs.

There are a number of strengths and weaknesses of this study. To our knowledge, this is the first study that has attempted to link reported craving with actual consumption, and only individuals who were able to provide plausible reports of energy intake[32,43,44] were eligible for participation in the study. However, assessment of food craving necessarily relies on self-reports, which may be inaccurate in both this study and others, and although the Craving Questionnaire developed by Weingarten and Elston (1991) has been noted to be an improvement in food craving measurement,[45] no data on reliability or validity of these assessments are available. Another limitation of this study was our inability to determine whether a food defined as a craved food was eaten on any particular occasion because it was craved at that time. Thus, the fact that craved foods were found to be consumed far more frequently in the food record than reported in the craving questionnaire might be due to reporting error, but could also be a result of those foods being consumed at times when they are not craved. Nevertheless, the decrease in the consumption of craved foods reported in the diet record after 6 months of ER is consistent with the decreased giving in to cravings and the trend of decreased consumption of craved foods reported in the food craving battery. It is also important to note that the generalizability to individuals dieting on their own with no provided food may be limited due to the high level of structure offered with 6 months of provided food in this study. These limitations notwithstanding, this is the first study of long-term changes in food cravings in a ER program and the first study to provide food to subjects for 6 months, and as such allows a greater degree of confidence in reported relationships between food cravings and other variables than is normally possible in studies of this kind.

Previous studies have reported that foods most commonly identified as craved are high in fat and carbohydrate, for example, chocolate, desserts and salty snacks.[6,42] The present study found similar types of reported craved foods, and further observed that cravings were not specific for one macronutrient such as carbohydrate as previously speculated.[46] Instead, we found energy density was an important defining characteristic of craved foods, being more than twice the average energy density of the solid component of the subjects' self-selected diets. The energy sources in our subjects' craved foods were primarily carbohydrate and fat (with protein in craved foods lower than the habitual diet on average), with typical craved foods having a mixture of fat and carbohydrate rather than being dominated by one nutrient or the other. Because separate neurological reward systems are thought to exist for fat and carbohydrate,[47,48] it

Table 5 Predictors of percent weight change after 6 months of energy restriction

Parameter	*Coefficient ± s.e.*	*Partial correlation*	P-*value*
Intercept	−17.97 ± 14.3	0.22	
Percent time gave in at month 6	0.08 ± 0.03	0.43	0.02
Energy density (kcal/g) of most craved food at month 6	−1.39 ± 0.58	−0.44	0.02
Baseline BMI (kg/m^2)	0.91 ± 0.48	0.36	0.07
Baseline age (years)	−0.36 ± 0.14	−0.45	0.02

Abbreviation: BMI, body mass index. Adjusted $R^2 = 0.31$, $P = 0.009$. Best fitting model predicting percent weight loss over 6 months of energy restriction from food craving variables, BMI and age. The model excludes those who answered 'no' to 'Have you experienced food cravings over the past 3 months?' at month 6. Percent weight change calculated as [(month 6–baseline)/baseline] × 100.

is possible that combinations of fat and carbohydrate give rise to greater reward[49] compared to single-nutrient foods. Likewise, the energy-dense foods may be more strongly craved because the greater amounts of carbohydrate and fat have a dose–response effect on reward. It is alternatively possible that cravings for highly energy-dense foods are a learned appetite for high-energy foods reinforced by consumption of the foods during periods of hunger.[12] It is also interesting to note that craved foods in our study were characteristically lower in dietary fiber content than the average diet of the subjects. The reason for this association is not known, and we speculate that perhaps not only the total energy content of the food influences reward, but also that the rate of digestion of energy is important (since one of the important properties of dietary fiber is that it slows digestion[50]). Further studies are needed to examine the effects of dietary fiber on food cravings and the biological basis for the associations.

There has been an ongoing controversy over whether food cravings arise primarily from a biological need for food, for example, developing through reinforcement following repeated consumption of high energy-dense foods in a state of metabolic food deprivation,[11,12] or whether cravings are more broadly due to associative conditioning between consumption of these foods and emotions, situations and other components of daily life.[51] Past studies have associated the frequency and strength of cravings with both susceptibility to hunger and external and emotional eating.[18] In this study, we found a statistically significant relationship between craving frequency and susceptibility to feelings of hunger as measured by the Eating Inventory, but a non-statistically significant relationship between the strength of food cravings and hunger score at baseline, which is consistent with the concept of multiple factors contributing to the development of food cravings. Owing to the small sample size tested, we were unable to find statistically significant differences in the changes in these associations over time and further research is thus needed in larger groups of subjects. Nevertheless, it may be important to note that, after 6 months of weight loss, significant relationships between hunger susceptibility and both the strength of cravings and the percentage of time individuals gave in to cravings were observed in this study, suggesting that craving strength may be more associated with susceptibility to hunger after ER compared to when food intake is less restricted. The finding that energy density of craved foods is higher in those individuals who lost a greater percentage of weight supports this suggestion, in that individuals who lost more weight presumably had a greater metabolic need for energy that was associated with cravings for the foods that would best provide it.

This study also provided data with practical implications for the development of obesity and success or failure of weight loss attempts. Many,[23,24,26] but not all,[19] previous studies that have examined food cravings during intentional dieting have found a decrease in reported food cravings with energy reduction. In contrast, cravings remained very common in our subjects after 6 months of ER and weight loss, with 94% of the participants reporting cravings over the past 3 months of dieting and a similar frequency of cravings reported at baseline before weight loss. Many of the past studies used low energy (1000–1200 kcal/day) or very low-energy (<1000 kcal/day) diets with monotonous food plans such as liquid supplements or high-protein diets.[19,23,24,26] The repetitive presentation of the same foods has been shown to increase sensory-specific satiety and decrease the cephalic phase response to food and this itself could be a plausible cause of reduced cravings.[23,24,52,53] In contrast, our ER plan used regular meals and foods, with the likely result that sensory-specific satiety and cephalic phase stimulations may not have been as suppressed as in other trials.[54] When considering the differences between this study and the previous studies using more monotonous regimens, it is important to note monotonous diets are effective for weight loss but are also recognized to be hard to sustain in the long term. From this perspective, the results obtained here may indicate that food cravings do not decrease with weight loss *per se* and that they need to be addressed as a potential cause of weight regain. Specifically, we found that although the frequency and strength of cravings did not decrease with time or differ between individuals who lost more vs less weight, greater weight loss was associated with a lower rate of giving in to cravings (as well as significantly higher energy density of craved foods as described above). These results, together with the statistically significant relationship between portion size of craved foods and adult lifetime high

BMI suggest that people attempting to lose weight and maintain weight loss may benefit from advice to accept that food cravings may not decrease in frequency and that reducing energy intake despite experiencing food cravings may need to involve decreased portions of craved foods and/or reduced frequency of giving in to such cravings.

In conclusion, cravings for energy-dense foods are common, appear to have origins rooted in both the expression of hunger susceptibility and in mechanisms unrelated to hunger, and do not decrease in frequency during a 6 month ER regimen consisting of provided regular foods. In this population of overweight but otherwise healthy women, lifetime high BMI was predicted by larger self-reported portion sizes of craved foods, while weight loss success was predicted by reduced frequency of giving in to the desire to eat craved foods. Combined, these findings point out important areas to emphasize in long-term weight loss programs, and further longitudinal studies are needed to confirm these findings.

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